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Bottom Backscattering Measured Off the Southwest Coast of Florida During the Littoral Warfare Advanced Development 98-2 Experiment

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Measurements of ocean bottom backscattering were performed in a shallow water environment off the southwest coast of Florida as part of the Littoral Warfare Advanced Development 98-2 Experiment. Scattering strengths were obtained from 1.5 to 4.5 kHz as a function of grazing angle. Scattering strengths were in the –25 to –35 dB range and showed no clear frequency dependence. The grazing angle dependence could be fit adequately by assuming a dependence of scattering strength on the sine of the grazing angle.

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BOTTOM BACKSCATTERING MEASURED OFF THE SOUTHWEST COAST OF FLORIDA DURING THE LITTORAL WARFARE ADVANCED DEVELOPMENT 98-2 EXPERIMENT

INTRODUCTION

The Littoral Warfare Advanced Development (LWAD) 98-2 experiment was conducted off the southwest coast of Florida in February/March 1998. The experiment area was located in the Gulf of Mexico, approximately 120 nm west of Key West, Florida.

Bottom reverberation is a potential source of clutter for active sonar systems operating in this littoral area. Bottom backscattering strength (BSS) in the 1.5 to 4.5 kHz band were calculated using direct path (i.e., source to bottom to receiver) measurements. Figure 1 shows the LWAD 98-2 bottom scattering sites. The lines within the boxes represent the ship track (drifting) during the scattering runs. Scattering runs 1 and 2 occurred with water depths of 150-165 m. The water depth was 120 m during scattering run 3.

The bottom interaction problem can involve multiple physical processes, all of which may contribute to the measured scattering strength: scattering from the water/sediment interface, scattering in the sediment volume itself, or scattering from the basement or a subsurface layer with a significant impedance mismatch. The frequency and grazing-angle dependence can reflect an enhancement of one mechanism over another, and given the variability of the littoral environment in sediment thickness, composition, and frequency-dependent attenuation, correct physical interpretation of bottom scattering strengths usually requires significant knowledge of the geoacoustic properties and structure of the subbottom. For regions where sand cover tends to be significant and results depend on specific characteristics such as sand layer thickness and homogeneity, there is greater potential for variability in frequency and site dependence.

Bottom scattering strength can be calculated by solving the sonar equation in the following form:

$$BSS = RL - SL + TL_s + TL_r - 10 \log A \tag{1}$$

where BSS is the scattering strength in dB, RL is the measured reverberation level in dB *re* $(1\mu\mathrm{Pa})^2/\mathrm{Hz}$, SL is the source level in dB *re* $(1\mu\mathrm{Pa})^2/\mathrm{Hz}$ at 1 m, TL_s is the transmission loss from the source to the ensonified patch on the bottom in dB, TL_r is the transmission loss from the ensonified patch on the bottom to the receiver in dB, and A is the area of the ensonified patch in square meters. The BSS results from LWAD 98-2 were calculated assuming a flat bottom. For performance modeling purposes, one would have to calculate the grazing angles of bottom interactions with respect to the actual bathymetry.

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During LWAD 98-2, BSS results were obtained at two sites. Data were obtained at seven frequencies (1.5, 2, 2.5, 3, 3.5, 4, and 4.5 kHz) at water depths ranging from 120 to 165 m, typically covering grazing angles of 8 to 44 degrees. Bottom backscattering measurements have been performed during three previous LWAD experiments: Focused Technology Experiment 96-2 (FTE 96-2), System Concept Validation 97 (SCV-97), and Focused Technology Experiment 97-2 (FTE 97-2). FTE 96-2 and SCV-97 data were obtained off the South Carolina coast and the results of the BSS measurements appear in [1,2]. FTE 97-2 data were collected at a site 16 nm southwest of Key West, Flordia and the results are reported in [3].

Results from these tests showed a strong dependence in scattering strength level on the presence or absence of a significant sand layer (> 20 m). Data taken with a significant sandy sediment thickness could be fit well by assuming a scattering strength proportional to the sine of the grazing angle, with proportionality constants of -25 dB to -30 dB. However, when the sediment is negligible and the underlying limestone is the scatterer, BSS values are 15-20 dB higher.

This report will present LWAD 98-2 BSS results as a function of frequency and grazing angle. The results will be compared with previous LWAD experiments from sites where the bottom has significant sandy sediment cover.

EXPERIMENT GEOMETRY AND DATA ANALYSIS

The bottom scattering tests were conducted from the research vessel LCU 1647 during LWAD 98-2. A 16-hydrophone vertical line array (VLA) and a source were deployed on a single cable, with the source 4 m above the center of the VLA receiving aperture. This resulted in a nearly monostatic measurement geometry.

The source was a ring-shaped transducer (USRD G81) that gave maximum (over the range of launch angles) root-mean-square source levels ranging from 187 dB (1500 Hz) to 197 dB (2500 Hz). The source beam pattern features a null in the upward direction and some flattening in the downward direction. This beam pattern gave maximum source level for all of the launch directions used to calculate scattering strength, so the deviations from the omnidirectional pattern did not affect the BSS calculation. However, the source directionality does help to mitigate sidelobe interference for very high grazing-angle returns, such as the initial acoustic interactions with the ocean surface and bottom. This allows extension of data validity to lower grazing angles. During the runs, the source was placed at two different depths (approximately 40 and 70 m). The waveforms were 50 ms gated continuous wave (GCW) signals at frequencies of 1.5, 2.0, 2.5, 3.0, 3.5, 4, and 4.5 kHz. Sets of 12 to 20 identical pings were transmitted at each frequency, with individual pings separated by 15 s. In some cases, a wavetrain was transmitted consisting of four adjacent 50 ms GCW signals in the sequence 2.0, 3.0, 2.5, and 3.5 kHz – the resulting scattering strengths were comparable to those obtained by transmitting the frequencies individually.

The bottom reverberation from the 50 ms pulses was received on the 16-hydrophone VLA. The hydrophones were spaced at 15.24 cm (6 in) which corresponds to half-wavelength spacings of 4920 Hz. Seventeen beams with cosine-spaced main response axes were formed from the 16-phone aperture, with most of the returns of interest coming from downward-looking beams closest to broadside.

After beamforming, power spectra were obtained by performing 50 ms Fourier transforms with

50 percent overlap over the length of the reverberation time series. A frequency band representing the total energy about the zero-Doppler peak was selected, and a time series including only the energy in this band was created for each ping. The direct arrivals for the pings were then temporally aligned and the various pings were averaged to produce a single reverberation curve for each beam and frequency bin. Integration over the roughly zero-Doppler spectral peak produced the total returned power as a function of time and beam. By calculating geometric spreading loss along each ray path, the transmission loss terms to and from the scattering patch were obtained. Finally, the computed beam pattern and raytrace were used to calculate the scattering patch area. From these inputs, BSS was calculated using Eq. (1) as a function of beam, frequency, and grazing angle. The standard deviations due to ping-to-ping variability within the sets of identical transmissions were $\pm$ 2 to 3 dB. The system calibration was computed to within 1 dB accuracy.

BOTTOM SCATTERING RESULTS

The LWAD FTE 97-1 experiment was performed in the same area as LWAD 98-2. Consequently, reference 4 was used to understand the surficial geology of the experiment site. To the west of the bottom scattering sites is Howell Hook reef which is a Pleistocene coral reef that acts as a sediment trap. Immediately to the east of the reef is an area consisting of a deep layer of foraminiferal sand. The sediment is composed of muddy calcareous sand [4]. Scattering run 3 occurred in this area of deep sand cover. Scattering runs 1 and 2 occurred between Howell Hook reef and the deep sand area. From a preliminary analysis, the sand layer is determined to be approximately 15-20 m thick.

Due to high seas, the data during scattering run 3 was contaminated with noise. In addition, there was excessive VLA tilt that violated the azimuthal symmetry of the problem. Consequently, the backscattering analysis for this data is not presented. Figures 2 through 5 show the BSS values from scattering run 2 at 2, 2.5, 3, and 3.5 kHz as a function of grazing angle. The source was at a depth of 40 m. The grazing angles for the source-to-scatterer and scatterer-to-receiver are similar (i.e., within tenths of a degree), so only one angle needs to be considered in the analysis. The average of the two grazing angles is the quantity plotted on the x-axis. The circles are scattering measurements (averaged over a set of 12 to 20 pings) from downward directed beams 4,5,6 and 7. The beam angles span 60 to 83 degrees relative to bottom endfire. The bold curve is the scattering strength averaged over these beams.

The bottom bold curve in the figures is the Mackenzie curve $-27 + 10\log(\sin^2\theta)$, a reference curve showing Lambert's law with a coefficient of -27 dB. This curve is the standard input to Navy performance models, with the selection of the -27 dB value originating in the work of Mackenzie [5]. For most LWAD scattering measurements [1,2], as well as measurements shown in McCammon [6], bottom backscattering data is flatter than the Mackenzie curve. This is also the case with data collected during LWAD 98-2. The data are better represented by assuming that the scattering is proportional to the sine of the grazing angle. The dashed curves in the figures represent $\mu + 10\log(\sin\theta)$ for μ = -20,-25 and -30 dB. (The dashed curve on the top is for μ = -20. The dashed curve on the bottom is for μ = -30.)

Figure 6 shows BSS as a function of grazing angle at 2000,2500,3000 and 3500 Hz during LWAD 98-2 scattering run 2 when the source was at a depth of 40 m. The BSS curves are the averaged scattering strength curves shown in figures 2-5. The BSS values are in the -25 to -35 dB range and show no frequency dependence. The values fall between the curves $-20 + 10\log(\sin\theta)$ and $-30 + 10\log(\sin\theta)$. Grazing angles ranged from 9 to 39 degrees.

Figure 7 shows BSS as a function of grazing angle at 1500,2000,2500,3000,4000, and 4500 Hz during scattering run 2 when the source was at a depth of 70 m. The BSS values are in the -30 to -35 dB range and show no frequency dependence. The values fall between the curves $-20 + 10\log(\sin\theta)$ and $-30 + 10\log(\sin\theta)$. Grazing angles ranged from 9 to 28 degrees.

Figure 8 is a scatter plot showing BSS as a function of grazing angle at 1500, 2000,2500,3000,4000, and 4500 Hz during scattering runs 1 and 2. The scattering measurements are represented as circles. The plot is a combination of data from multiple deployments with the two source depths (40 and 70 m) and repeated transmission sequences. Grazing angles ranged from 8 to 44 degrees. The BSS values are in the -25 to -35 dB range and fall between the curves $-20 + 10\log(\sin\theta)$ and $-30 + 10\log(\sin\theta)$.

SUMMARY

During LWAD 98-2, bottom backscattering strengths were measured at two sites off the southwest coast of Florida. The water depths at these sites ranged from 120 to 165 m. Scattering runs 1 and 2 occurred at a site between Howell Hook reef and the deep sand area. The water depth at this site ranges from 150 to 165 m and the sand layer is approximately 15-20 m thick. Scattering run 3 occurred at the second site, in an area consisting of a deep layer of foraminiferal sand. Due to high seas, the data during scattering run 3 was contaminated with noise. In addition, there was excessive VLA tilt that violated the azimuthal symmetry of the problem. Consequently, the backscattering analysis for the data collected during scattering run 3 is not presented.

The scattering strengths measured during runs 1 and 2 were in the -25 to -35 dB range and showed no clear frequency dependence. Grazing angles ranged from 8 to 44 degrees. The grazing angle dependence could be fit adequately by assuming a dependence of scattering strength on the sine of the grazing angle. The scattering data tended to indicate μ values in the -20 to -30 dB range. These results agree closely with scattering data from previous LWAD experiments where the bottom had a significant sand layer (> 20 m) and BSS values had μ values in the -25 to -30 dB range.

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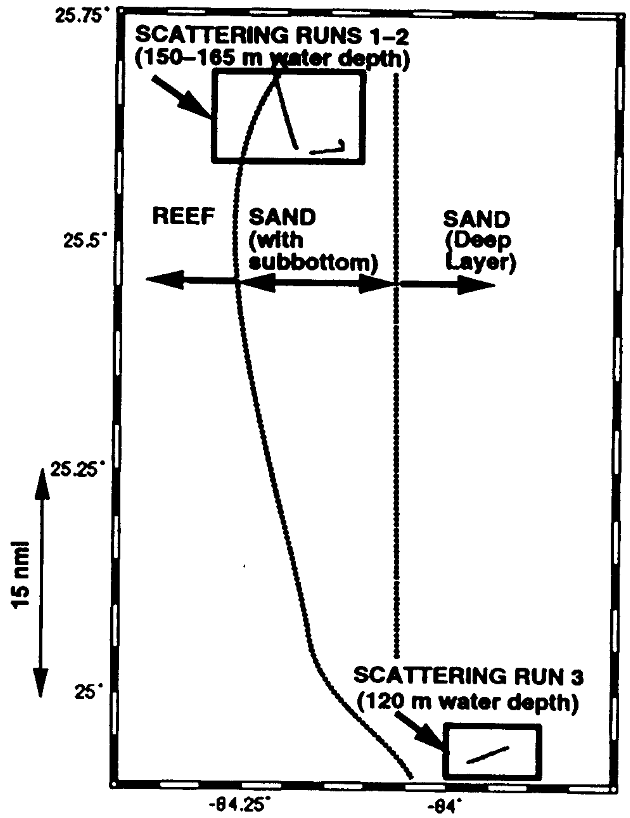

Fig. 1 — LWAD 98-2 bottom scattering experimental sites. The lines within the boxes represent the ship track (drifting) during the scattering runs.

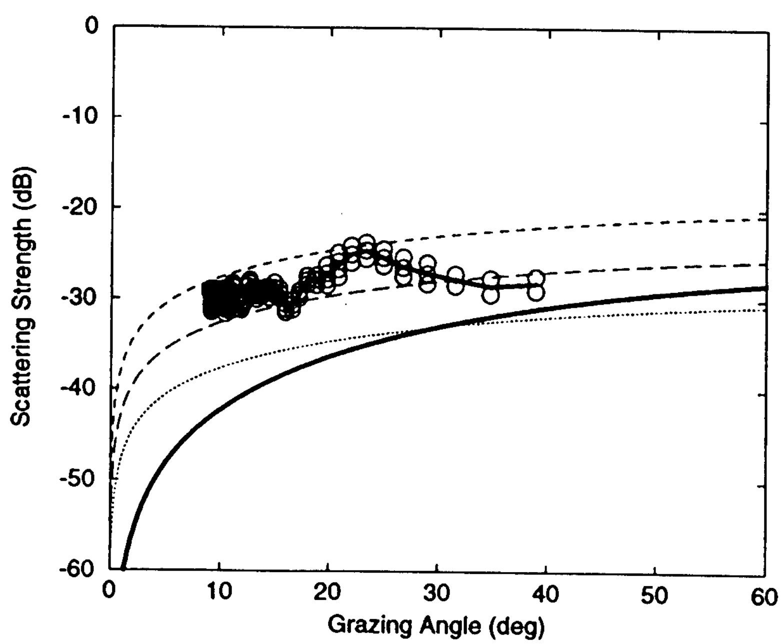

Fig. 2 — Bottom backscattering strength as a function of grazing angle at 2000 Hz during scattering run 2. The source was at a depth of 40 m. The circles are scattering measurements from beams 4,5,6 and 7. The bold curve is the scattering strength averaged over these beams. The dashed lines represent $\mu + 10\log(\sin\theta)$ for μ = -20,-25 and -30. The Mackenzie curve is shown as the bottom bold curve.

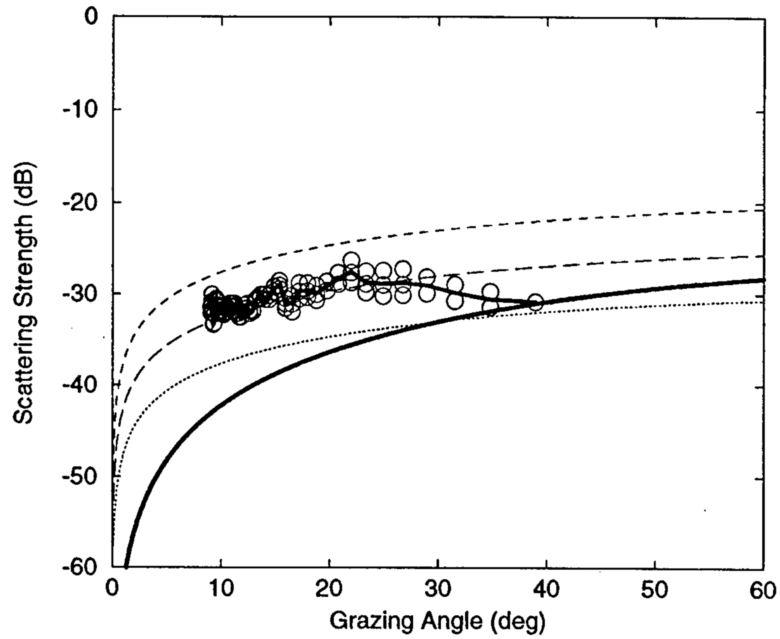

Fig. 3 — Bottom backscattering strength as a function of grazing angle at 2500 Hz during scattering run 2. The source was at a depth of 40 m. The circles are scattering measurements from beams 4,5,6 and 7. The bold curve is the scattering strength averaged over these beams. The dashed lines represent $\mu + 10\log(\sin\theta)$ for μ = -20,-25 and -30. The Mackenzie curve is also shown.

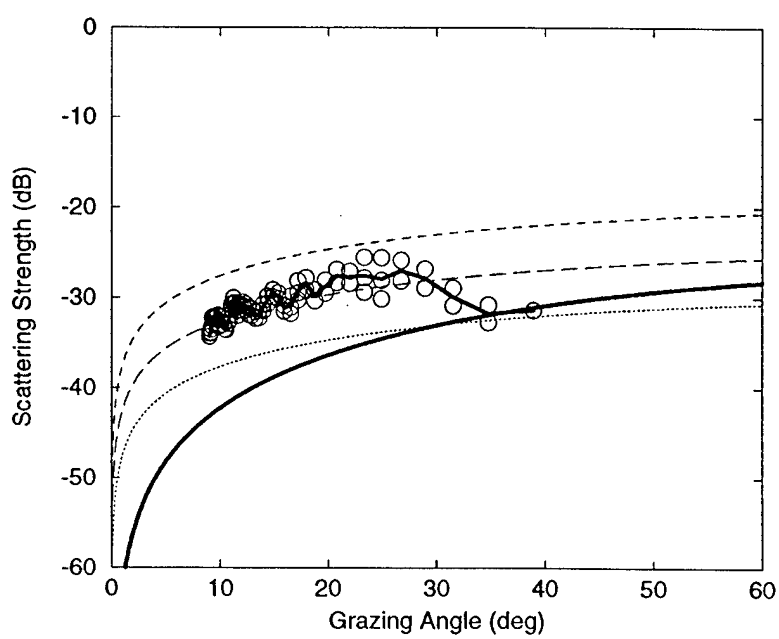

Fig. 4 — Bottom backscattering strength as a function of grazing angle at 3000 Hz during scattering run 2. The source was at a depth of 40 m. The circles are scattering measurements from beams 4,5,6 and 7. The bold curve is the scattering strength averaged over these beams. The dashed lines represent $\mu + 10\log(\sin\theta)$ for μ = -20,-25 and -30. The Mackenzie curve is also shown.

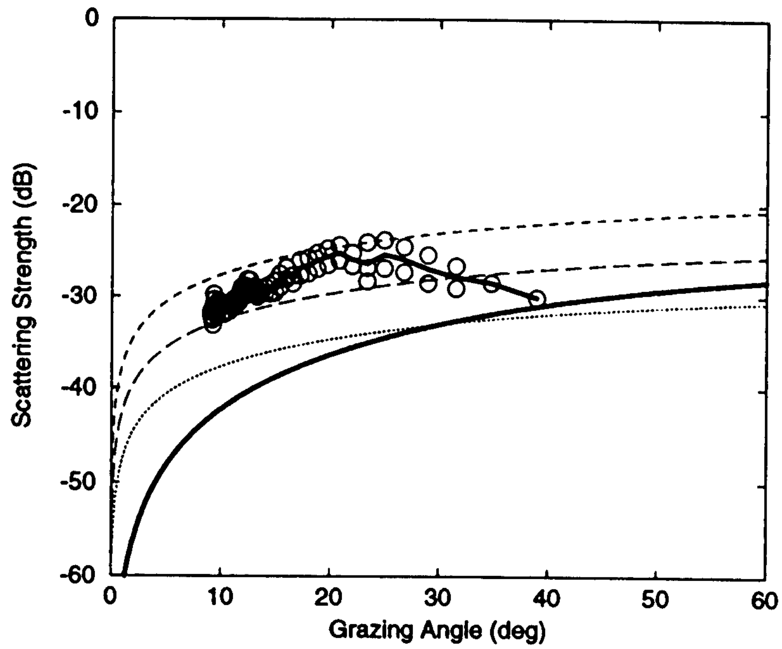

Fig. 5 — Bottom backscattering strength as a function of grazing angle at 3500 Hz during scattering run 2. The source was at a depth of 40 m. The circles are scattering measurements from beams 4,5,6 and 7. The bold curve is the scattering strength averaged over these beams. The dashed lines represent $\mu + 10\log(\sin\theta)$ for μ = -20,-25 and -30. The Mackenzie curve is also shown.

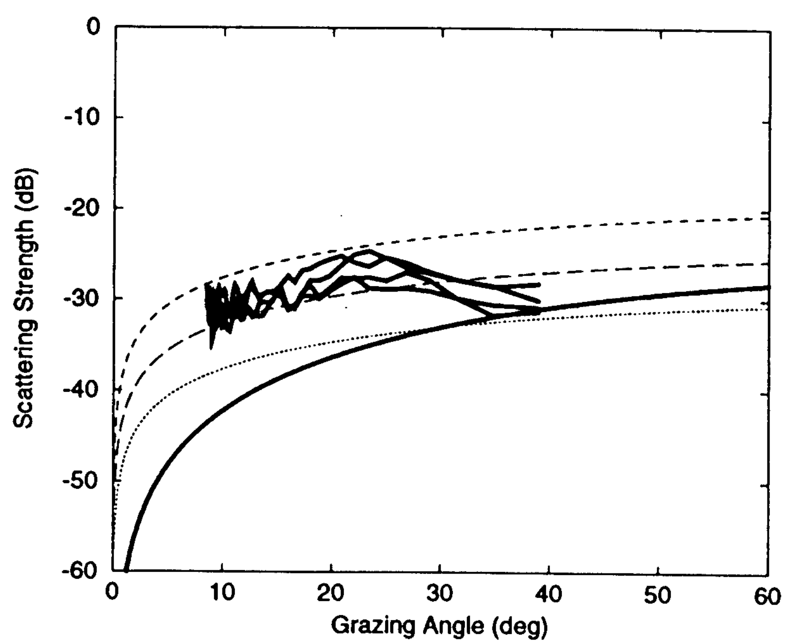

Fig. 6 — Bottom backscattering strength as a function of grazing angle at 2000,2500,3000 and 3500 Hz during LWAD 98-2 scattering run 2. The BSS curves are the averaged scattering strength curves shown in figures 2-5.

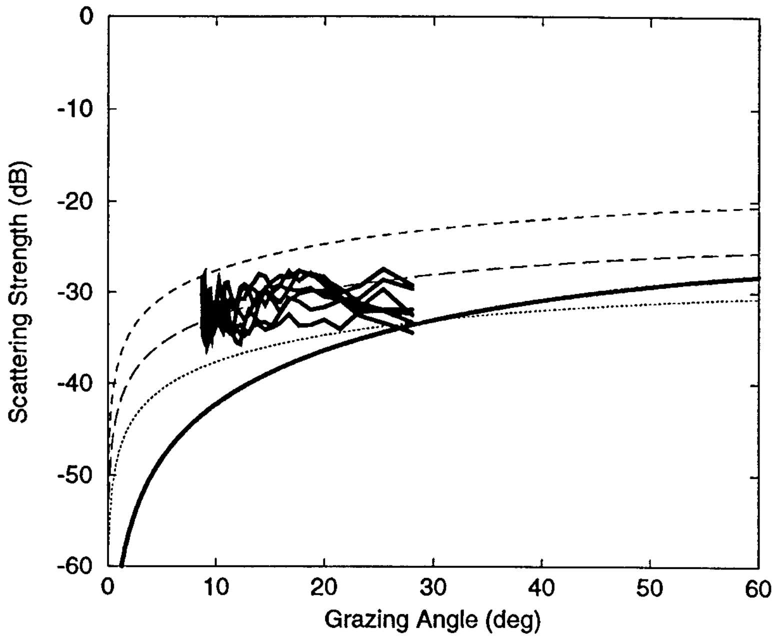

Fig. 7 — Bottom backscattering strength as a function of grazing angle at 1500,2000,2500,3000,3500,4000, and 4500 Hz during LWAD 98-2 scattering run 2. The source was at a depth of 70 m. The BSS values fall between the curves $-20 + 10\log(\sin\theta)$ and $-30 + 10\log(\sin\theta)$.

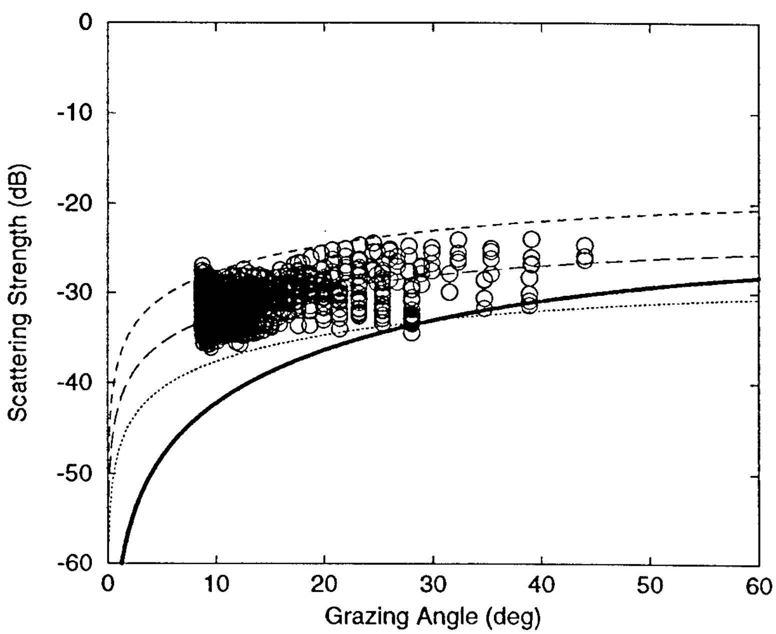

Fig. 8 — Bottom backscattering strength as a function of grazing angle at 1500,2000,2500,3000,3500,4000, and 4500 Hz for scattering runs 1 and 2. The BSS values (represented as circles) fall between the curves $-20 + 10\log(\sin\theta)$ and $-30 + 10\log(\sin\theta)$.